Removing Signal Intensity Inhomogeneity from Surface Coil MRI Using Discrete Wavelet Transform and Wavelet Packet

Fa-Hsuan Lin[1,2], Ying-Jui Chen[3], John W. Belliveau[2], Lawrence L. Wald[1,2]
[1]Harvard-MIT Division of Health Sciences and Technology
[2]Department of Radiology, Massachusetts General Hospital NMR Center, [3]Department of Electrical and Computer Engineering, Boston University

Abstract- **We evaluate a combined discrete wavelet transform (DWT) and wavelet packet algorithm to improve the homogeneity of magnetic resonance imaging when a surface coil is used for reception. The proposed algorithm estimates the spatial sensitivity profile of the surface coil from the original anatomical image and uses this information to normalize the image intensity variations. Estimation of the coil sensitivity profile based on the wavelet transform of the original image data is found to provide a robust method for removing the slowly varying spatial sensitivity pattern.**

Keywords **- MRI, wavelet packet, discrete wavelet transform, surface coil**

I. Introduction

Surface coils offer the potential for a 2 to 5 fold increase in sensitivity compared to volume coils. Despite of this signal-to-noise advantage, surface coils are not used regularly for many applications because of their small region of coverage and their intrinsically inhomogeneous reception profile. The limited coverage of a single small surface coil can be extended by using a phased array of multiple coils [1]. The phased array technique also improves the homogeneity of the images in the plane of the array, but the image intensity is still significantly brighter near the coils than deeper in the brain. Thus, the surface coil detector has an inherently inhomogeneous reception profile that leads to a variation in intensity across the image. This significantly degrades the utility of the images for evaluation of pathology in the cortex.

To correct the inhomogeneity of the surface coil MRI due to the modulation of coil reception sensitivity profiles, several approaches have been studied to estimate the coil profile, which is used to correct the measured inhomogeneous MRI [1-12]. These methods use either a theoretically generated model [1, 3, 13] of the coil or the information in the image itself [2, 4, 6-8] to generate the expected coil sensitivity map. In the first case, knowledge of the location and orientation of each surface coil is required in addition to a B_1 field map generated from the coil geometry. In the second case, the coil intensity profile can be approximated by a low-pass filtered version of the original image. The low pass filter based approximation of the surface coil profile requires *a priori* knowledge of the anatomy and coil fall-off in order to determine the appropriate cut-off spatial frequency which separates the low frequency variations due to coil fall off from the higher spatial frequency variations due to the anatomy.

Here we propose a solution to correcting surface coil image intensity variations using post-hoc processing of the original surface coil image. The method identifies edges in the image and uses this information to improve the estimation of the coil sensitivity map. The slowly varying intensity changes comprising the estimated coil sensitivity map are determined from a filter bank implementation. This method allows the comparison of multiple levels of spatial filtering. The optimum level of filtering is determined by an automated analysis of the spatial variance in the corrected images. The coil map estimation also includes an iterative maximum projection method to improve the approximation of the coil sensitivity profile near the edge of the head. We also use a wavelet packet analysis to improve the spatial frequency resolution when estimating the coil sensitivity profile. To have a better visualization of correct images without enhancing the background noise, users can fine-tune the reconstruction depending on the scanner SNR and imaging anatomy.

II. Methodology

The images from a surface coil can be viewed as the product of the true anatomical image and a function representing the spatial modulation imposed on the image by the surface coil reception profile. Thus, the true homogeneous image, $C[\vec{n}]$, is modulated by the coil sensitivity, $S[\vec{n}]$, to generate the observed inhomogeneous image, $Y[\vec{n}]$, where $\vec{n}$ is the position vector in 3D space. Thus our goal is to get an estimate, $\hat{S}[\vec{n}]$, of the true coil sensitivity profile, $S[\vec{n}]$. The corrected reconstruction image, $\hat{C}[\vec{n}]$, which represents an approximation of the true anatomical image is then expressed in terms of the ratio of the original data $Y[\vec{n}]$ and the estimated coil sensitivity profile.

$$\hat{C}[\vec{n}] = \frac{Y[\vec{n}]}{\hat{S}[\vec{n}]}, \vec{n} \in R^3 \quad (1)$$

Estimation of coil sensitivity profile using discrete wavelet transform (DWT) has been reported in our previous publication [14] Figure (1) illustrates the algorithm. The advantage of this proposed algorithm is the automatic multiple-level coil sensitivity profile estimation adapted to different imaging protocols, since no prior knowledge about the coil position, orientation, and geometry is assumed in the algorithm. Also, we applied an iterative maximum projection on each level of coil sensitivity profile estimation in DWT to avoid the underestimation of coil sensitivity at the vicinity of high contrast brain-air boundary.

However, conventional DWT limits the spatial frequency resolution because only the low-pass bands are iteratively decomposed. On the other hand, wavelet packet algorithm can improve the frequency resolution by further decomposing other subbands. Our previous DWT algorithm can search the

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle Removing Signal Intensity Inhomogeneity From Surface Coil MRI Using Discrete Wavelet Transform and Wavelet Packet	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Harvard-MIT Division of Health Sciences and Technology Boston University, MA	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom.

Abstract

Subject Terms

Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU

Number of Pages
4

optimal level of DWT estimation. Therefore we increase the spatial frequency estimation using wavelet packet between one level above and one level below the optimal level determined by the DWT-based estimation. This combined DWT-wavelet packet approach can thus estimate the coil sensitivity profile with computational efficiency and with improved estimation accuracy.

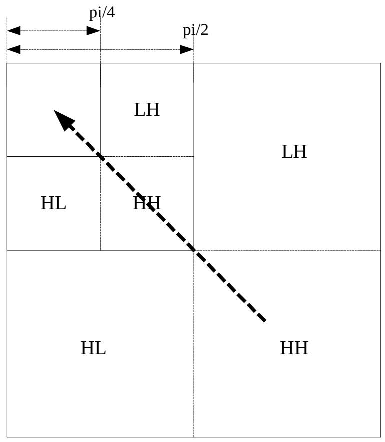

Fig. 1 Dyadic DWT decomposes the original signal into subbands. Only low-pass signals in all dimensions are filtered iteratively for a computationally efficient estimation of coil sensitivity profile, which is reconstructed by zeroing out all high-pass subbands above different cut-off frequencies.

Figure 2 illustrates the details about incorporating wavelet packet analysis in DWT estimation of the coil sensitivity profile. Here we assume that level 2, which has an equivalent cut-off frequency at pi/4, is the given optimal level from the DWT estimation. To search a possibly better solution than the one found in DWT, we decompose one level above and below the optimal level into subbands (between thin dashed lines) for finer spatial frequency resolution, which is implemented by wavelet decomposition on both high-pass and low-pass bands of signal in each dimension. After zeroing out the high-pass information, spatially slowly varying coil profiles are reconstructed from the wavelet packets coefficients (the light gray area), in addition to the DWT decomposition coefficients (the dark gray area).

Daubechies 9/7 filter banks [15] were used in the estimation of the coil sensitivity map using wavelet packets. This filter bank has three vanishing moments to provide smooth cubic polynomial approximation of the input signal. Intel Pentium® III processor (Santa Clara, CA) and Matlab (Natick, MA) were used in implementation environment.

III. RESULTS

Image acquisition

Images were acquired using a General Electric Signa 1.5T scanner (Milwaukee WI) with a home built four-element bilateral surface coil array. The array elements consisted of overlapping 8cm diameter surface coils. The imaging pulse sequence was either a spoiled gradient echo (SPGR) 3D volume exam (TR/TE/flip = 40ms/6ms/30^{o}), partition thickness = 1.5mm, matrix = 256 x 256, 124 partitions, Field of View = 18cm. The array elements were placed over the subject's temporal lobes.

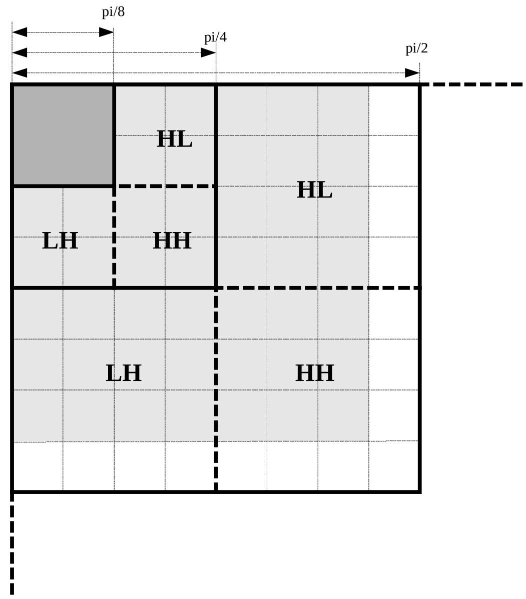

Fig. 2 Wavelet package analysis on all subbands of images can increase the spatial frequency resolution when estimating the coil sensitivity profile. Bold solid lines represent the divisions of frequency analysis in DWT. Given an optimal level from DWT, wavelet packet decomposition on all subbands (dashed lines), including both high-pass and low-pass signals, can improve the coil sensitivity profile estimation. Reconstruction incorporating both DWT subband (dark gray region) and wavelet packet coefficients (light gray region) provides finer spatial frequency resolution.

Image inhomogeneity correction

Our previous DWT-based results revealed that for the input image acquired from the bilateral phased array with image matrix of 256 X 256 pixels, level 5 gives the optimal estimation of the coil sensitivity profile in terms of the most homogeneous reconstructed image. This DWT estimation of coil sensitivity profiles and the associated corrected images are shown in Figure 3.

Given level 5 being the optimal level of reconstruction from DWT, we decomposed the images between level 4 and level 6 using Daub 9/7 filter bank for finer spatial resolution. 2 levels of wavelet packets were performed between level 5 and level 6 to generate 4 frequency bands between pi/16 and pi/32. Additionally 3 levels of wavelet packets were performed between level 4 and level 5 to generate 8 equal bandwidth analyses between pi/8 and pi/16. Totally 13 reconstructions were obtained with equivalent cut-off frequency between pi/32 and pi/8, and they are shown in Figure 4.

After correction, visualization of the temporal and frontal cortex and deep sub-cortical structures including putamen and caudate body is considerably improved. To numerically assess the improvement in homogeneity, the image intensity before and after correction was scaled so that the mean pixel value in the caudate nucleus was 70.0. Frontal white matter near the caudate then had a mean pixel value of 100.0 in both images. With the before and after images scaled to provide the same caudate to white matter contrast, the image correction method was found to reduce the peak to peak

variance in the brain parenchyma by a factor of 17. Also, we created a brain parenchyma mask excluding the background, scalp, skull and cerebrospinal fluid space to quantify the variance change after the correction. The image with smaller variance inside the brain parenchyma mask is considered to be more homogeneous. The 6th wavelet packet reconstruction, which has an equivalent cut-off frequency of 21*pi/128, provides a more homogeneous image than the DWT optimal level 5, which has a cut-off frequency of pi/16. This is shown in Figure 5.

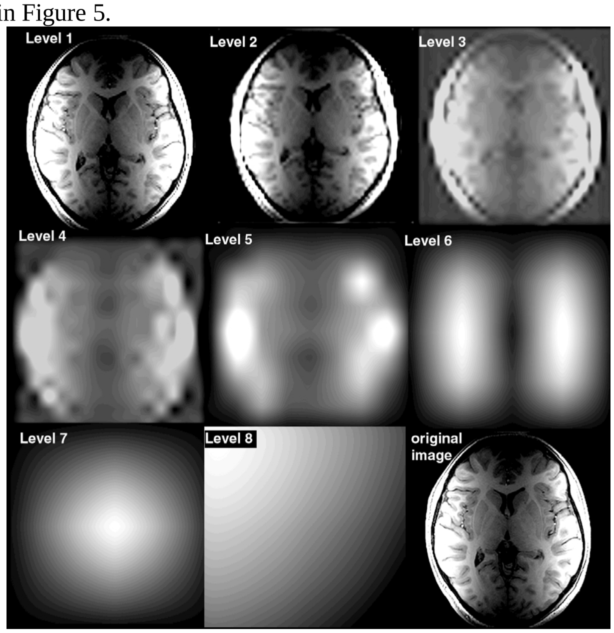

Fig. 3 Estimated sensitivity profiles of 8 levels of DWT decomposition and reconstruction. Level 5 is the optimal estimation in that the corrected image has minimum image variance.

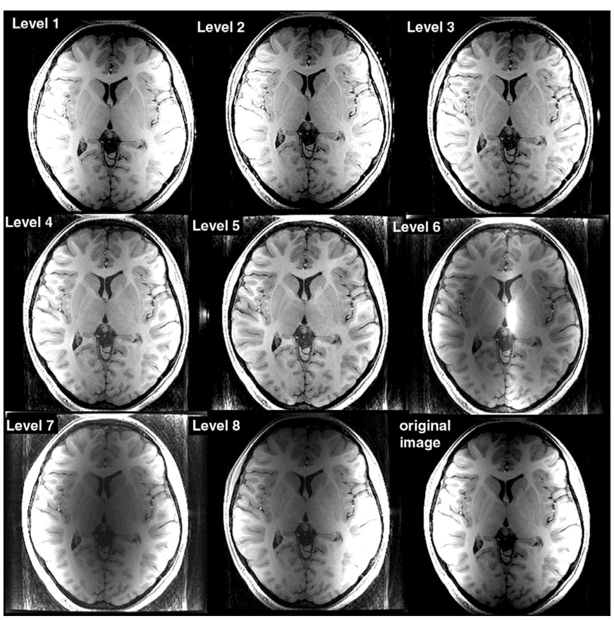

Fig. 4 Eight levels of correction by Daub97 filter bank using DWT. Reconstruction at level 5 (cut-off frequency pi/16) provides the optimal reconstruction in terms of user-defined ROI homogeneity.

IV. Conclusion

In this paper, we propose an automatic method to correct the inhomogeneity of surface coil MRI using a combined discrete wavelet transform and wavelet packet analysis for finer spatial resolution as we estimation the coil sensitivity profile. The Daubechies 9/7 filter bank was found to have good computational efficiency and approximation of coil sensitivity map. The method uses neither prior physiological knowledge nor knowledge of the electro-magnetic properties or locations of the RF coil. Reconstructed images show improved visibility, which allows region near the coils to be viewed with the same window and level settings as regions far from the coil. This improves visualization of the cortical areas and deep gray structures in the basal ganglia.

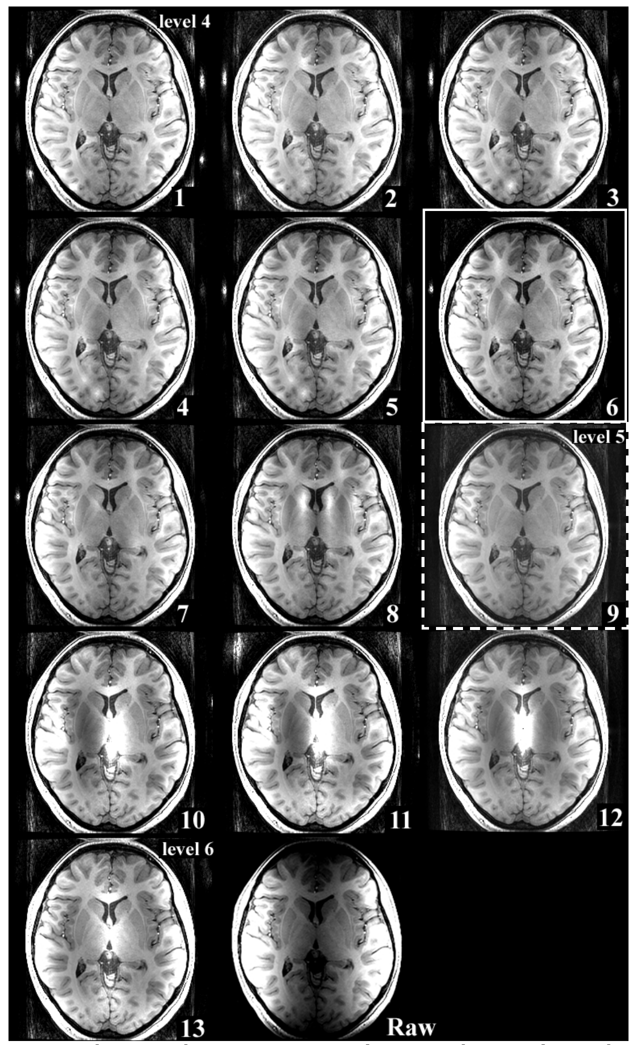

Fig. 5 Thirteen inhomogeneity-corrected images by wavelet packet estimation of coil sensitivity profile using Daub97 filter bank between DWT level 4 (cut-off frequency pi/8) and DWT level 6 (cut-off frequency pi/32). The 6th wavelet packet reconstruction (in solid frame; cut-off frequency 21*pi/128) provides better coil sensitivity profile estimation than the DWT optimal level 5 (in dashed frame) in terms of smaller brain parenchyma variance.

REFERENCES

[1] P. B. Roemer, W. A. Edelstein, C. E. Hayes, S. P. Souza, and O. M. Mueller, "The NMR phased array," *Magn Reson Med,* vol.16, pp.192-225, 1990.

[2] L. L. Wald, L. Carvajal, S. E. Moyher, S. J. Nelson, P. E. Grant, A. J. Barkovich, and D. B. Vigneron, "Phased array detectors and an automated intensity-correction algorithm for high-resolution MR imaging of the human brain," *Magn Reson Med*, vol.34, pp.433-9, 1995.

[3] S. E. Moyher, D. B. Vigneron, and S. J. Nelson, "Surface coil MR imaging of the human brain with an analytic reception profile correction," *J Magn Reson Imaging*, vol.5, pp.139-44, 1995.

[4] P. A. Narayana, W. W. Brey, M. V. Kulkarni, and C. L. Sievenpiper, "Compensation for surface coil sensitivity variation in magnetic resonance imaging," *Magn Reson Imaging*, vol.6, pp.271-4, 1988.

[5] W. W. Brey and P. A. Narayana, "Correction for intensity falloff in surface coil magnetic resonance imaging," *Med Phys*, vol.15, pp.241-5, 1988.

[6] L. Axel, J. Costantini, and J. Listerud, "Intensity correction in surface-coil MR imaging," *AJR Am J Roentgenol*, vol.148, pp.418-20, 1987.

[7] M. S. Cohen, R. M. DuBois, and M. M. Zeineh, "Rapid and effective correction of RF inhomogeneity for high field magnetic resonance imaging," *Hum Brain Mapp*, vol.10, pp.204-11, 2000.

[8] K. Van Leemput, F. Maes, D. Vandermeulen, and P. Suetens, "Automated model-based bias field correction of MR images of the brain," *IEEE Trans Med Imaging*, vol.18, pp.885-96, 1999.

[9] H. Mihara, N. Iriguchi, and S. Ueno, "A method of RF inhomogeneity correction in MR imaging," *Magma*, vol.7, pp.115-20, 1998.

[10] B. D. Ross, P. Bland, M. Garwood, and C. R. Meyer, "Retrospective correction of surface coil MR images using an automatic segmentation and modeling approach," *NMR Biomed*, vol.10, pp.125-8, 1997.

[11] J. W. Murakami, C. E. Hayes, and E. Weinberger, "Intensity correction of phased-array surface coil images," *Magn Reson Med*, vol.35, pp.585-90, 1996.

[12] P. Irarrazabal, C. H. Meyer, D. G. Nishimura, and A. Macovski, "Inhomogeneity correction using an estimated linear field map," *Magn Reson Med*, vol.35, pp.278-82, 1996.

[13] S. H. Lai and M. Fang, "A new variational shape-from-orientation approach to correcting intensity inhomogeneities in magnetic resonance images," *Med Image Anal*, vol.3, pp.409-24, 1999.

[14] F.-H. Lin, L. L. Wald, Y.-J. Chen, and J. W. Belliveau, "Estimation of coil sensitivity map and correction of surface coil magnetic resonance images using wavelet decomposition," presented, at, International Society of Magnetic Resonance in Medicine, Brighton, UK, 2001.

[15] G. Strang and T. Nguyen, *Wavelets and filter banks*.Wellesley, MA, Wellesley-Cambridge Press, 1996.